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by

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YIDOYU and Its Application to Aircraft Design

YIDOYU Service Group

Xianxue SUN, Qihao LONG, Bingchen PAN and Wenpu CHEN

Abstract This paper is to introduce the essential techniques, special points, and a sketch on the procedure organization of the multi-constraint design optimization system for aircraft structures (YIDOYU), and also to reintroduce the present status of its systematic applications. From the results of some actual examples, YIDOYU is shown to be a practical design optimization system to have ability and efficiency in solving different structural optimization problems.

Key wordsstructural analysis, optimal design, approxim ation technique, constraint derivative.

I. Introduction

The multi-constraint design optimization system for aircraft structures (YIDOYU) is a large-size application software, mainly used in designing aircraft wing-surfaces, and can also be used in making design optimization for general thin-skin structures under a variety of constraints of structural shapes. Its research was carried out under the leadership of Department of Aeronautics,

Bureau of Science and Technology by 623 (the unit of the group leader), 631, 611, 603 and 605 research institute, in association with Nanjing Academy of Aeronautics, etc., altogether for 6 units to spend 4 years until its completion. It was approved by all the relevant departments and bureaus in November of 1982, and then won the first prize in 1983 for the aeronautic technology accomplishment and the second place in 1985 in the national advancement of science and technology.

In 1983 the system service group was established, the YIDOYU was applied in some actual examples, manuscripts were published, the procedure was transplanted, the system was compiled, and revisions in the programs were made, so as to have made a great progress in various directions. Up to now design computations of YIDOYU on 7 actual examples have been carried out, 6 manuscripts have been published, it used machines for 5 units, produced 4 editions, realized graphic displays (laid it down later) (by connecting to CADAM and SUPERTAB), completed incorporation with the CIEM system. The actual steps have been explained, its system capability is fairly complete, easy to use, the methods reliable, the calculation efficiency fairly high, and received good evaluations from users.

This paper is mainly to introduce the systematic sketch of YIDOYU and the present status of its applications.

II. The Sketch of the System

1. Main Functions and Special Points

YIDOYU utilizes the mathematical programming techniques to optimize designs, capable under a variety of constraints, such as stress, displacement, natural frequency, flutter speed, static aeroelasticity (various control efficiency, divergence) and minimum size constraint. It can carry out load-calculation, normal and abnormal aerodynamical calculations, calculation of softness coefficients, computations of various analytic

derivatives for displacement and stress analysis, natural vibration analysis, flutter characteristics analysis, static aeroelasticity analysis, and fully stressed design.

The elemental storages of the system contain 9 kinds, namely levers, boards and beams, etc. and mostly they are metallic structural units, small amount of complex material units, standard units, broad units and mass units. It also has material storage depots, wing-type depots, structure depot and other typical structural design data, to provide analyses and optimization in design selections.

The system uses well-established Structural Statics and Dynamics as the analytic methods. By use of the Cholesky dissociation method to solve equation $KU = P$, in which the dissociated results of K is preserved, while the other parts will be used; using the softness matrix method, one can get "compression" of the dynamical model from the static model, and thus by use of the QL method, one solves for the eigenvalue of dynamic characteristics of the structure. By use of the Yacob method to calculate abnormal aerodynamical force; in the flutter analysis, first the Mach number (Ma) has to be fixed, then the density of the air flow (p) and the compressibility (1/K); by use of the revised LR method to find the characteristic value, then by use of the revised Laguere asymptotic method to find the characteristics of the flutter; by use of the kernel functional method one can calculate the aerodynamical influence coefficients needed in analyzing aerostatical elasticity.

The optimization method of this system uses approximation concepts and also the series unconstrained minimizing techniques (SUMT); and the suggested methods are the trapezoidal rule, revised Newton's rule, the conjugate trapezoidal rule, the DFP measure-variance rule, and the BFGS measure-variance rule to solve the unconstrained extreme value problems, the quadratic parabolic method and the golden division method are used to investigate one-dimensional problems.

By use of the mathematical programming techniques, one can tackle large size complex structural designs under a variety of constraints, and the key is efficiency. The YIDOYU utilizes a series of approximation techniques and the analyze-search methods, and reaped quite a bit of striking successes.

(1) By use of the variable-coupling method to reduce the number of variables. The idea of the YIDOYU design is to divide the structural model into several structural blocks (each block contains several normal structural elements of the same kind) and to let the yardstick A of each block receive 2 kinds of design variables D to control. In this way, one uses only several tens of variables to represent several hundreds or even several thousands of elemental parameters. The coupling relationship is shown by

$$\{A\} = \{T\} \{D\}$$

where [T] is the altitude-diluted transformation coefficient matrix.

(2) By use of the key position design method to reduce the number of constraints. Based on the force-transmitting characteristics of the structure and from the experiences in designing, one can designate a representative "key element" to each block out of all the elements, to start a redesigning process with the participation of the stress-constraints, and from the stress-state of the key element one can go back to find the design variable D. Usually, the limit is set by the number of the key elements, but the process can greatly reduce the computation efforts.

(3) By use of the effective variable groups to reduce the number of variables. In optimizing designs, one can consider that for each constraint there is a corresponding effective variable group. Each block has a user-designated variable which affects each constraint, and by use of this variable one can vastly reduce the computation efforts.

(4) By use of the capacity-limit e of the constraints one can sweep off temporarily the excessive portion of the effective constraints to reduce the number of constraints.

(5) One may approximate the equation which expresses the constraint structures, and thus the frequency of analyses on the completed structure can be reduced.

(6) By use of the analytic method one can find the constraint derivatives for all the existing kinds.

This system is totally used in using the advanced analytic derivative method to obtain the equations for stress, displacement, frequency, static elasticity, divergence velocity pressure, and flutter velocity, etc.; as compared to the differential method, it not only has a higher precision but also a great efficiency, and such quality was one of the problems of the successful key techniques presented by this system.

Beside being considered for its functions and efficiency, the system also provides quite a few user-friendly steps.

(1) The front-and-back position processing. By use of the data to produce the model blocks which automatically generate data for all kinds of models and thus is capable to greatly reduce a vast amount of artificial writing-down of the primitive data; the calculated results have 3 ways of communicating, namely "Printout of the reporting equations", "diagram communication" and "Figure presentation". It has already established interfaces for CADAM and SUPERTAB graphic software to be able to draw and to display tens of graphs, clearly and directly.

(2) Facing up to the users' jargons. The users can depend on their own computation habits to go through all kinds of analyses and optimizations of designs. Under the MVS operation system, the execution procedure can be controlled by the JCL (Job Control Language) and operations are convenient.

(3) It is capable of interrupting the processes and restarting them and it has also the error-diagonizing ability. The YIDOYU can be compared with any similar kind of systems made here or abroad to show many obvious special points. According to America's NASA published <Aeronautics Technical Reports> of 1984 (see STAR N84-10768*), it lists 6 YIDOYU's special points as follows : (1) Utilizing the mathematical programming techniques, it is capable of optimizing the design problems in wing-surface structures of aircraft under a variety of constraint conditions, and also capable to broaden the constraint types, if need exists; (2) It is capable to take care of all kinds of the wing-surface structures which have something to do with the control system and also the wing-surface structures connected to the fuselage; (3) It can also establish some needed practical stabilizing computation methods by infusing the allowable amount of stresses; (4) It has a stronger than average capability to process the pre- as well as post-solution situations; (5) It is equipped with the ability to handle the users' own jargons; and (6) By use of the analytical method, it can compute various kinds of response-derivatives and it is capable to use many kinds of optimization models and approximation techniques, all of which obviously will improve the design efficiency.

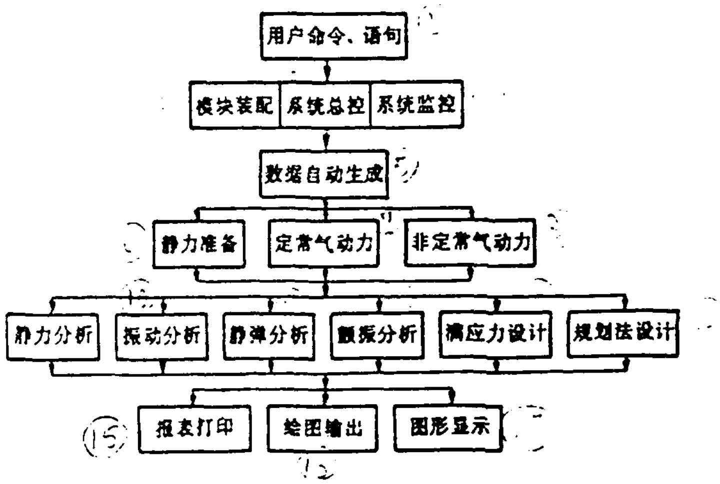

Fig. 1. A sketch of the YIDOYU system structure

(1) User's command - language (2) Model-block facility
(3) System's supreme control
(4) System supervising control
(5) Data automatic generation (6) Static preparation
(7) Normal aerodynamical force
(8) Abnormal aerodynamical force
(9) Static Analysis (10) Vibration analysis
(11) Static elasticity analysis (12) Flutter analysis
(13) Fully stress design
(14) Design by the programming method
(15) Report printout (16) Diagram dispatch
(17) graphic display

2. Organizing Routines

This system utilizes subroutines and multi-routine organizations, characterized by 9 equal functioning principal routines, 34 functioning model-blocks, and several community routines; it adopts the structures made of model-blocks, to execute programs easily; it adopts no pattern, long records, multi-documentation systems of block-forming structures, to execute data-supervision and -dissemination by utilizing database and community blocks; it makes the system distribution to several organizations; it practices sufficient utilization of empty space; it uses 2 kinds of execution formats, namely the "investigating attitude" (an execution accompanied by testings) and "computing attitude" (an execution accompanied by no testing) ; it is made for users' command or language through interfaces. Adopting all the above-mentioned routine method, it has already

satisfied a lot of demands with its functions existing in the system, and improved the system's computation efficiency, and thus it has become a large scale power house capable of realizing design optimizations under a variety of constraints.

See Fig. 1 for the structure of the YIDOYU system.

III. Actual Application Examples After the YIDOYU was thrown in for execution, 17 types of models have been computed for pre- and post-design (see Fig. 2) and all got excellent results.

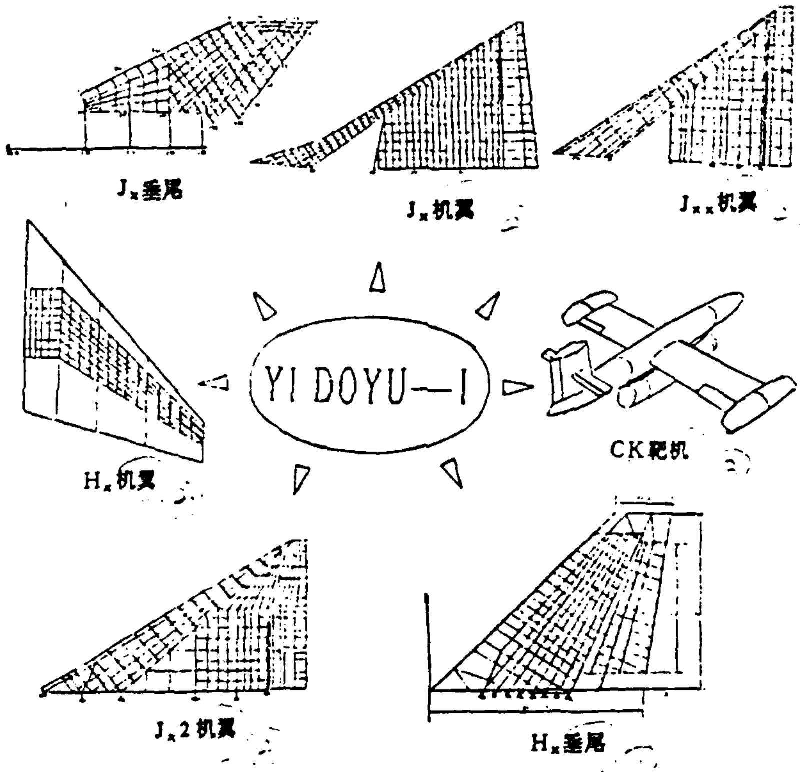

Fig. 2. Actual Application Examples

(1) Vertical tail (2) Fuselage-wings (3) Drone-plane

1. Analysis of the fuselage-wings of a certain type of drone-plane and its optimization

In search of some type of drone plane (see CK droneplane in Fig. 2), the wing must have some leeway and the wing tips have suspending cabins so that all kinds of structural analyses can be carried out and the design can be optimized.

The plane had single wing, double wall type flat-straight fuselage wings, with total 220 rivet-points, 660 degrees of freedom, 4 sets of static outer loads : A, A', B and L-twisted lower part. Taking the up- and down-skins into account, one finds in total 10 design variables of large beams with protruding edges and belly boards.

Static analyses showed that displacement and stress distribution agreed with the regulations, and as compared with the tested values, the difference was about 5 % ; in the static elasticity analysis (on the efficiency and divergence) the results were reasonable; in the vibration analysis, the vibration frequency and the tested values agreed; the flutter analysis (Vf = 603.04 m/s) agreed with the value computed by the users.

In optimizing designs, the fully stress design (FSD) was assumed as the initial values, then under the constraints of elastic efficiency, divergence velocity pressure, vibration frequency, flutter speed, displacement and the lower limit of the variables, etc., the programming techniques were carried out to optimize the design (M.P). FSD went through 4 times of selecting-and-replacing to reduce the weight by 9.85 kg ; M. P went through 5 times of selecting-and-replacing to satisfy all the constraint conditions, and as compared to the initial design, weight reduction was 4.3 kg. For the design selecting process, see Fig. 3 and Table 1. From them one can see that through optimization of design, the structural efficiency has improved. For instance, the final design reduced its weight by 3 % from the

initial one, and the flutter velocity on the other hand was raised by 5 %.

This plane was analyzed again for the flutter with 3 kinds of the suspending wing-tip cabins, the user selected the most appropriate arrangement for the suspending cabins, and this drone-plane made a successful test flight.

Table 1 THE SELECTION RESULTS FOR THE FUSELAGE-WING DESIGN OF THE DRONE-PLANE

		总重 W(kg)	弹性效率 η	发散速压 V_D(GPa)	振动频率 ω(Hz)	颤振速度 V(m/s)	位移 U(cm)
初始设计		121.3	1.033	3.43E-4	6.98	603.04	-23.5
FSD		111.4	1.051	2.45E-4	6.80	500.98	-27.1
M.P. 迭代	1	112.5	1.047	2.65E-4	6.81	531.93	-26.6
	2	113.6	1.044	2.84E-4	6.81	559.98	-26.1
	3	114.7	1.041	3.04E-4	6.82	585.74	-25.7
	4	115.8	1.039	3.24E-4	6.82	609.68	-25.3
	5	116.9	1.037	3.43E-4	6.83	632.10	-25.0
约束限			1.0	0.39E-4	6.5	300.0	-25.0

(1) The initial design
(2) Total weight
(3) Elastic efficiency
(4) divergence velocity pressure
(5) vibration frequency
(6) flutter velocity
(7) displacement
(8) M.P. selection and replacement
(9) Limit of constraints

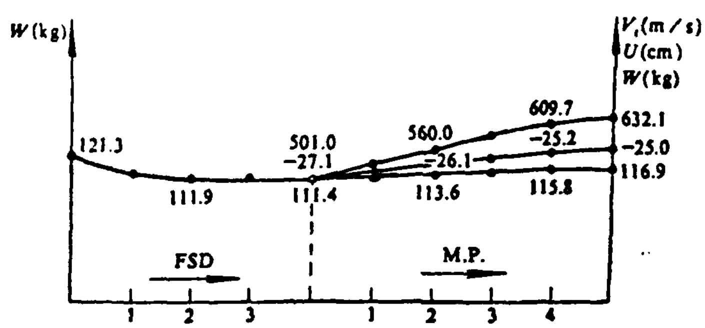

Fig. 3. The selection process for the fuselage-wing design of the drone-plane

2. The design computation for the vertical tail of a certain plane

At the stage of detail designing of a certain airplane, the flutter of the vertical tail should be raised to its critical velocity, in executing the flutter analysis and the optimization of the design.

Because the structure was symmetrical between the up- and down-side, just one half of the computation (see the model in Fig.2 for Hx vertical tail) was carried out, with 257 rivet points, 771 degrees of freedom, thus 1,013 items in total. Selecting the skin and beam-strips, etc., one would come up with 13 structural parameters, and the edge of the directional rudder had 5 units of weight elements which became the optimization variables; in total the computations were carried out on the flutter characteristics under 17 kinds of circumstances and 60 multi-situations.

The computation showed that by adjusting stability of the wing-tip skin thickness, the effect of the flutter velocity could be improved. By allowing the wing-tip skin (between N7* - 24 *) from 1.8 mm adjusted to 2.5 mm, the structure weight was increased by 3.14 kg and the flutter velocity was raised by 49 m/s. The user can quickly revise his design policy by referring to such computed results.

To test the computed results, the user made a wind-tunnel experiment (in the year of 1985) for the designed flutter model, and the tested results agreed very well with the computed results, see Table 2.

3. Design a drawing policy for the fuselage-wing of a certain airplane

The fuselage model of the plane had 3 back-side control points (see Jx X fuselage wing in Fig.2), due to the up- and down-symmetry, only one half of the computation was needed for

371 rivet-points, 951 degrees of freedom, thus 1267 items in total, and 7 sets of static outer loads.

For this example, computations were carried out for the strength, vibration, flutter and static aeroelasticity efficiency; by compared with totally metallic material, the complex material was computed for static and dynamic force characteristics and the efficiency of the auxiliary wings. The whole computation took 20 days to complete the work load of 3 - 4 months. In Table 3, the comparison of these policies is shown.

Table 2. COMPARING THE COMPUTATIONS ON THE HX VERTICAL TAIL WITH THE EXPERIMENTAL RESULTS

	振动频率(Hz)	颤振频率(Hz)	颤振速度(m/s)
计算结果	4.93 13.84 14.80 23.32	11.5	44.2
试验结果	4.89 13.10 15.25 23.25	10.8	49.0

(1) Computed results
Tested results
(2) Vibration frequency
(3) Flutter frequency
(4) Flutter velocity

Table 3. COMPARISON AMONG SEVERAL COMPUTATION POLICIES

	固有频率(Hz)	颤振速度(m/s)	静弹效率	结构重量(kg)
全金属	12.18 31.50 38.16 48.26 56.01 69.33 72.33 83.81	655.56	0.16277 0.35546	1291.96
部分复材	12.38 32.24 39.76 56.03 59.83 73.53 77.35 89.73	682.56	0.16580 0.35546	1187.42
全金属(带2枚导弹)	11.06 16.67 21.29 31.88 38.97 48.32 55.41 68.55	931.7	同全金属方案	

(1) Characteristic frequency
(2) Flutter velocity
(3) Static elasticity efficiency
(4) Structural weight
(5) Totally metallic
(6) Partially complex material
(7) Totally metallic (carrying 2 guided bombs)
(8) The same totally metallic policy

4. Assembling together the YIDOYU and CIEM systems

The YIDOYU is one of the important softwares to bring the CIEM (the Computer Integrated Engineering and Manufacturing) system into the assembly. Following the assembly demand, the beginning and ending are compiled, then the front and rear position are programmed, to complete the process of U.F format's database/adjustment storage (FE depot), to realize the software connection with CADAM and SUPERTAB graphic, to compute 2 actual examples of Hx and Jx, to program and display the needed graphics. The YIDOYU has already become the important constitutional part of CAD/CAM. Fig.4 and Fig.5 show, respectively, the model of Hx fuselage wing and the displacement of Jx2 fuselage-wing.

From this practice, the YIDOYU is recognized to be a practical system used in optimizing the designing work for the wing-surface under a variety of constraints. The service subroutines will continue to improve the execution of the system, such as increasing graphic pretreatments and complex material analyses and optimizing functions for designs.

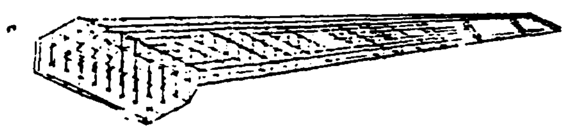

Fig. 4. Hx Fuselage-wing model

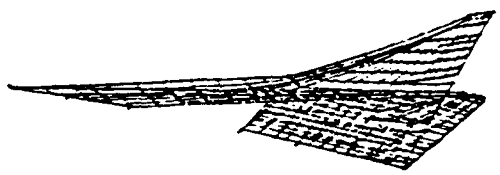

Fig. 5. Jx2 fuselage-wing displacement

The actual computation in the stage of programming of the system and responsibility of the analyses were due to Mong-Hak Lin and Guanxun Li; support and participation in the service work of the system came from Heiliang Ting and Zhuming Li, quching Wang, Fan Chang and Shiaxun Sun; the user representatives were Hianshi Chang, Pingkue Liao, Haijiang Chin, Moksan Chen, Moliang Ye, Sumu Lung, Zhuquo Chang, Quzhun Xing, Guanchin Xun, Suchin Liu, and Duanven Fu.

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